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13. ABSTRACT *(Maximum 200 words)*

Strategic Analysis, Inc. (SA), in collaboration with George Mason University (GMU), demonstrated feasibility of several aspects of a novel packaging concept for SiC devices that could withstand temperatures in excess of 650°C. SA proved the feasibility of laser welding for attaching SiC devices to a transparent substrate. This concept eliminates the need for intermetalic solders for bonding and die attachment while utilizing pass under lead-throughs. These package simplifications provide an alternate solution to CTE mismatch problems found in typical hybrid ceramic devices. Since this is a dominant failure mechanism, laser welded devices have inherent stability at necessary operating temperatures. Further effort will see full development of hermetic sealed laser welded SiC device packages. Conformal coatings used for seal can provide simple yet either thermally conductive or insulative protection to circuits. Predicted performance of this novel package is well beyond 650°C based on reduced failure points. This new packaging scheme will permit SiC devices to be inserted into multi-chip module format, thus increasing the commercial and military use of SiC devices.

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Laser weld, flip chip, SiC, high temperature

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PHASE I. TECHNICAL OBJECTIVES

1. Show that a laser tack welded contact can be made through borosilicate glass and will survive temperatures above 650°C including temperature cycling. Examination of other metal interfaces such as a gold brazing compound might be necessary should welds be insecure. Also chip and substrate heating may be necessary to improve the mechanical and electrical integrity. Laser welding has the capability of processing dissimilar metals which may become appropriate. There is also the question of laser power and time, i.e., excessive heating could cause pad lift-off, cratering or glass cracking before good contact is made.

2. Show that borosilicate glass can be processed in a similar fashion to Si wafers using refractory metals and silicon nitride. 7059 glass can be obtained in high quality and optical planarity without question but metal sticking coefficients and SiN growth processes are not well established, though it's encouraging to know that CdTe and other solar cells have been developed on this glass without problem. (Mo has also been used on 7059 in development of CIGS solar cells with good adhesive results)

3. Show that a laser welded lid arrangement will provide a hermetic seal for all thermal operating environments. The base substrate and lid are both borosilicate but the intermediate material is metal. This is necessary to prevent the possible cutting of leads to the outside. The coefficient of thermal expansion (CTE) of the lid and substrate are identical but problems could occur for the intermediate weld metal. Additionally lip and substrate size may be restricted by the bonding strength. This will be established in experiments.

4. After establishing the above objectives show that the integrated package concept works for the intended temperature range using a SiC rectifier.

ADDITIONAL OBJECTIVES:

1. Alternate substrate investigation. Borosilicate has a poor CTE match at higher operating temperatures which may lead to thermal cycling failures. In addition resistivity drops cause leakage currents through the substrate. Current alternates include AlN, transparent ceramic, SiC, Si, and zero expansion glass.

2. Conformal hermetic seal. A simplified hermetic arrangement using a conformal coating of sol-gel or CVD ceramics is under investigation to reduce processing costs and laser treatment cycles while improving reliability.

RESULTS OF EFFORT

Strategic Analysis, Inc. in conjunction with George Mason University proved the core concept of its high temperature packaging approach. First two molybdenum coated (1µm thick films) 7059 borosilicate glass slides were successfully laser welded together face-to-face using a modified laser trimming station at Naval Research Labs. Pulse width variation and laser dwell times were adjusted to yield the best welds. Second, individual pads were laser scribed onto another Mo coated glass slide to form the contact points for CREE SiC JFETs purchased under this contract. The devices were inverted and held down with photoresist and aligned with source and drain chip pads directly over Mo pads. A YAG (1.06µm) laser beam projected through the substrate welded the SiC device to the moly pads. Figure one illustrates the basic concept of a laser welded flip chip arrangement.

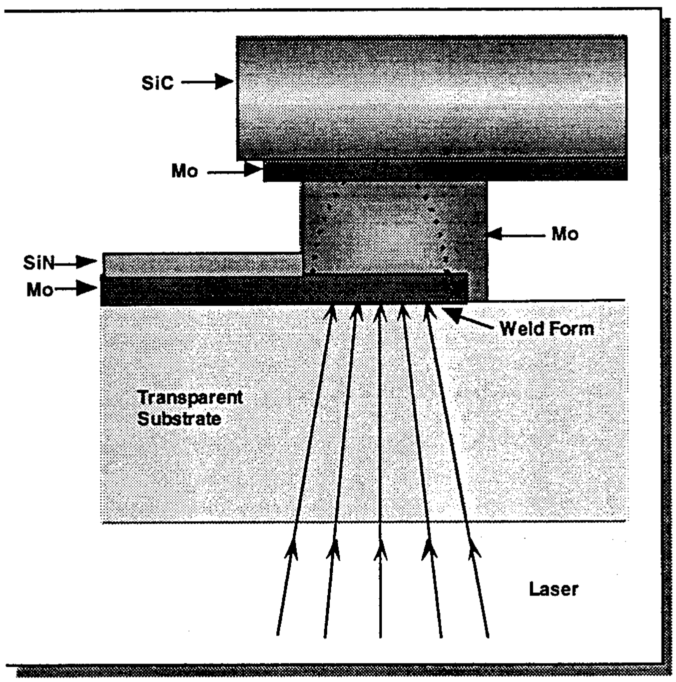

Figure 1. Basic flip chip laser tack welding concept.

A laser weld made through the glass substrate formed a good mechanical bond between chip and underlying pads. Electrical continuity was tested through measurement of the channel resistance and found to be acceptable. The attached JFET resistance was comparable to a CREE JFET packaged device as can be seen in the experimental details. Mechanical integrity was excellent, bonds broken purposely were found to fail at the moly/glass interface and not at the weld or die itself. This was also shown during the welding tests of face-to-face moly coated glass slides. Pads were defined using laser scribing instead of photolithography

EXPERIMENTAL DETAILS

Welding was carried out on a Florod laser system at Naval Research Laboratory (NRL) through a cooperative agreement between George Mason and NRL. Several different experiments were carried out to determine welding thresholds for combinations of power, pulse width and scan rate. This was accomplished using "face-to-face" moly/glass and SiC/moly/glass interfaces.

Laser specifications: YAG operating at 1.06 microns (1.16eV) with a beam diameter of 10 microns and total power of 4 Watts.

Weld Specifications: Pulse frequency was set at 5kHz for all experiments with current adjustments controlling power flow to weld sites. Scan rates (feed rates) were adjusted using nominal numbers including 100, 50 , 10, 5, 1 where 100 translates into 25mm/sec, 50 = 12.5mm/sec, etc. Experiment showed the cleanest welds began at currents of 11 Amps and feed rates of 3. Additional adjustments opened a range of between 12 and 15 Amps with either single or double passes.

Techniques: Weld pads were defined using laser scribing instead of photolithography due to simplicity. Figure two illustrates the arrangement used for die attachment. Laser scan patterns were varied between straight scan lines and a "quilted array as shown in figure three. The dimensions shown were typical of the experimental geometry. Table one exhibits a typical array of parameter variation. After weld threshold was reached all welds effectively attached die. At low powers, resistance was high due to incomplete melting. Higher powers and dwell time tended to remove moly isolating the weld area from external contact. This again raised resistance, however, the exact cause - contact or sheet resistance of the devices was not ascertained. Figure four shows a CREE JFET connected to moly pads.

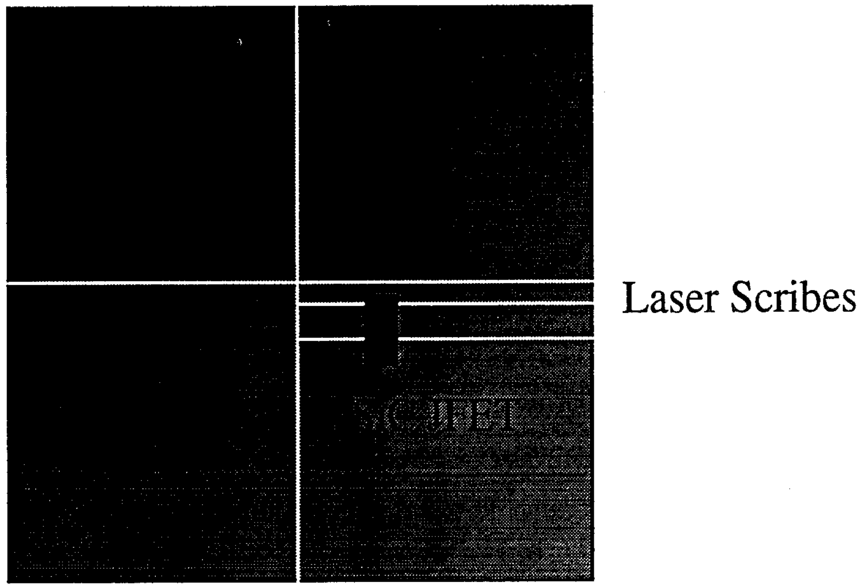

Figure 2. Moly coated glass with scribe lines and JFET in place for welding.

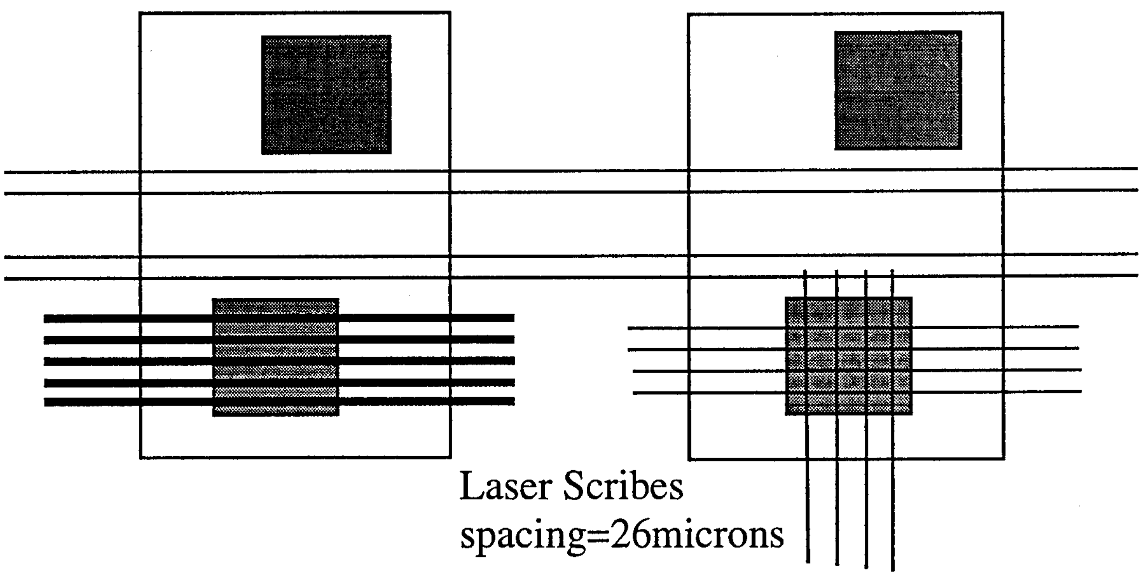

Figure 3. SiC JFET as seen through the substrate with laser weld patterns used to attach die in several experiment. Single stripes showed the best results.

Table One. Experimental variation on weld power, threshold = .8 Watts at this feed rate

Experiment	Amps	Watts
1	12	.175
2	12.5	.345
3	13	.55
4	13.5	.78
5	14	1.04
6	14.5	1.25
7	15	1.5

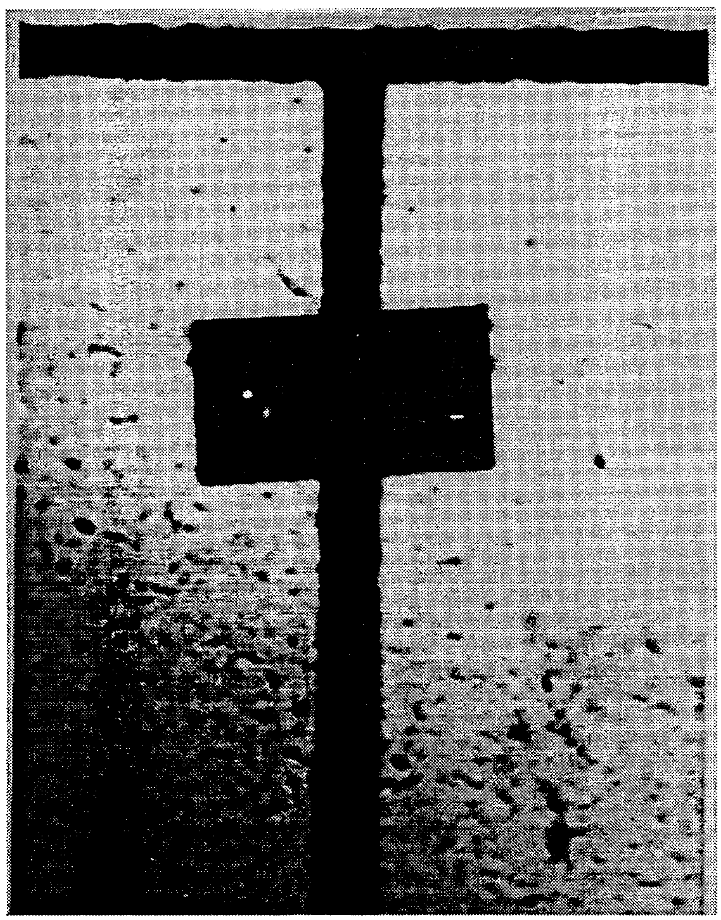

Figure 4. Phase contrast micrograph of welded SiC JFET.

Figure 5 shows a comparison in current and voltage measurements between the welded JFETs and identical pre-packaged JFETs. This data was measured at NRL and is included in Appendix A. Note the higher series resistance of the welded package. This is a result of incomplete contact area due to the narrow weld lines. Adhesion issues, "tape pull test", indicated excellent mechanical stability. Molybdenum, however is a refractory and thus difficult to melt. One possibility is to deposit Si prior to weld to generate a silicide contact chemistry which has been shown to be very effective for SiC.

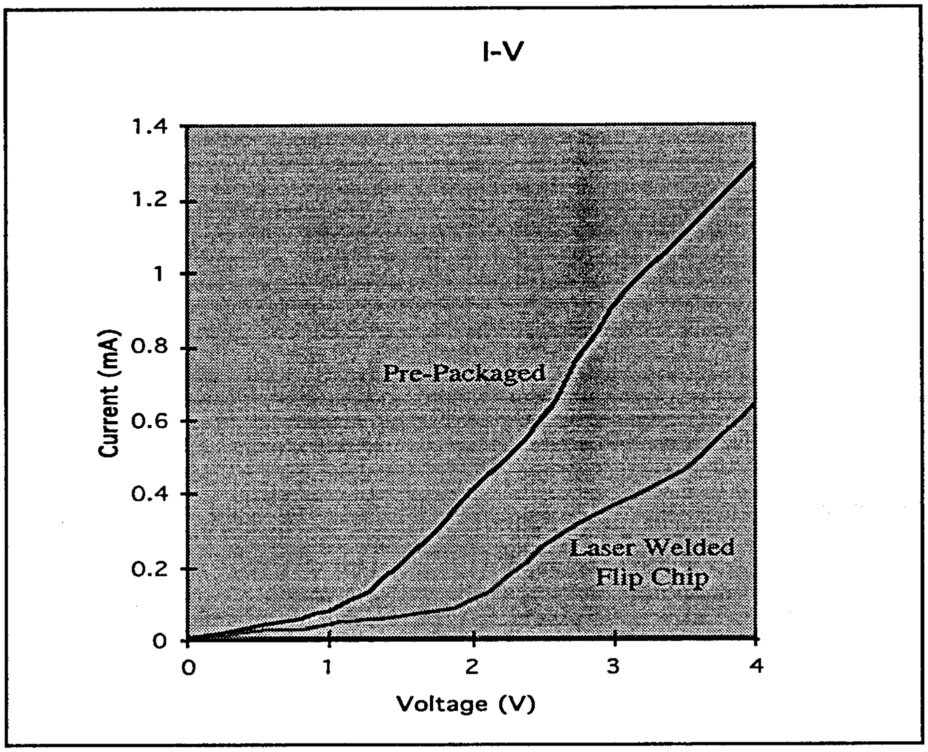

Figure 5. I-V comparison for welded JFETs and CREE pre-packaged JFETs.

No thermal analyses were performed as the weld failure could not be isolated from CTE mismatch due to the poor substrate characteristics. Better substrate selections for future analysis will allow full testing capabilities.

RESEARCH HIGHLIGHTS

As mentioned, the most significant highlight is our proof of the laser welding concept as it applies to flip chip high temperature packaging. This design allows for the removal of solders and other intermetallics known to be detrimental at high temperatures. In addition flip chip removes the need for die attach alloys also shown to be a problem at operating points intended in this research. The leads are fed out of the package using a "pass under" arrangement which eliminates lead-throughs and reduces seal problems.

CTE mismatch problems are also reduced due to limited number of materials that are required. Additionally, a transparent substrate allows optical signal transport with little packaging modifications. In general Strategic Analysis can now move ahead with engineering modifications of it's design to improve contact quality and thus survivability. This work is very significant in that it side-steps many of the most serious issues associated with conventional hybrid package approaches.

As became apparent in Phase I, borosilicate glass is an inappropriate substrate for higher temperatures due to its increasing expansion coefficient and conductivity as a function of temperature. Therefore, Phase I also included substrate analysis to find a suitable replacement for glass. Some initial work was performed on AlN as a possible candidate. AlN has an excellent CTE match with SiC as can be seen in Figure 6. Thermal conductivity is also appropriate as can be seen in Figure 7, along with its other properties. These figures were taken from "A Review of High Temperature Electronics Packaging, Final Report" by Wayne Johnson in the Workshop on High Temperature Electronics, June 6-8, 1989. The optical transmission characteristics of AlN were measured at the Naval Research Laboratory. AlN substrates were subjected to powers up to 2.5 Watts with no clear delivery of energy to the contact interface to form the weld. Unfortunately AlN proved not to be a good substrate for laser welding because the grain structure of the substrate scattered light to the point of attenuation. The AlN substrates were subjected to powers up to 2.5 Watts with no clear delivery of energy to the contact interface to form the weld. In addition AlN has a long standing history of metalization adhesion problems. This coupled with its translucency has eliminated it as a viable candidate.

Zero expansion glass was reviewed via meetings with Corning and its specialty glass product line. If packages were going to stay at some preset temperature or remain in a high temperature ambient a CTE set point could be designed to best match the SiC CTE. However these materials are a mix of amorphous and microcrystalline structures and thus possess CTE ranges that during transients and cycling would lead to failure. Poly and single crystal materials are required. Silicon has an excellent CTE match with both SiC and moly. However, the bandgap is 1.12eV, the YAG is 1.16eV. Clearly an attenuation problem would dissipate energy and cause too much local heating. SiC polycrystalline substrates were obtained but their mm thickness' (and defects) reduced the laser energy below weld thresholds. We attempted to weld directly through the SiC die itself since its bandgap is optimal and single crystal. Unfortunately the CREE devices were gold coated on both sides. We are in the process of lapping away the gold to gain access through the SiC.

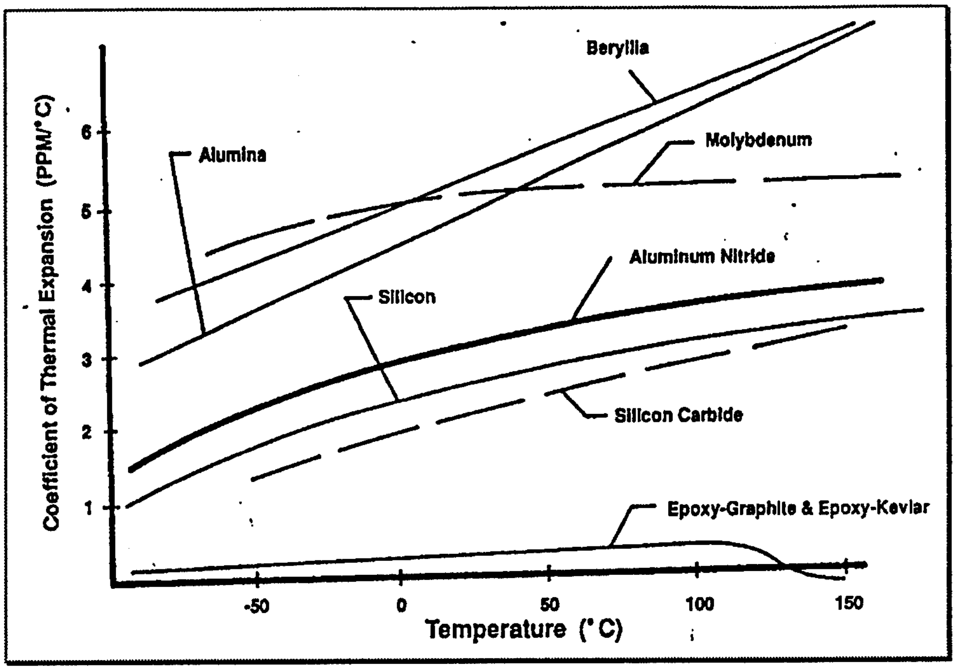

Figure 6. CTE of various component materials for in packaging.

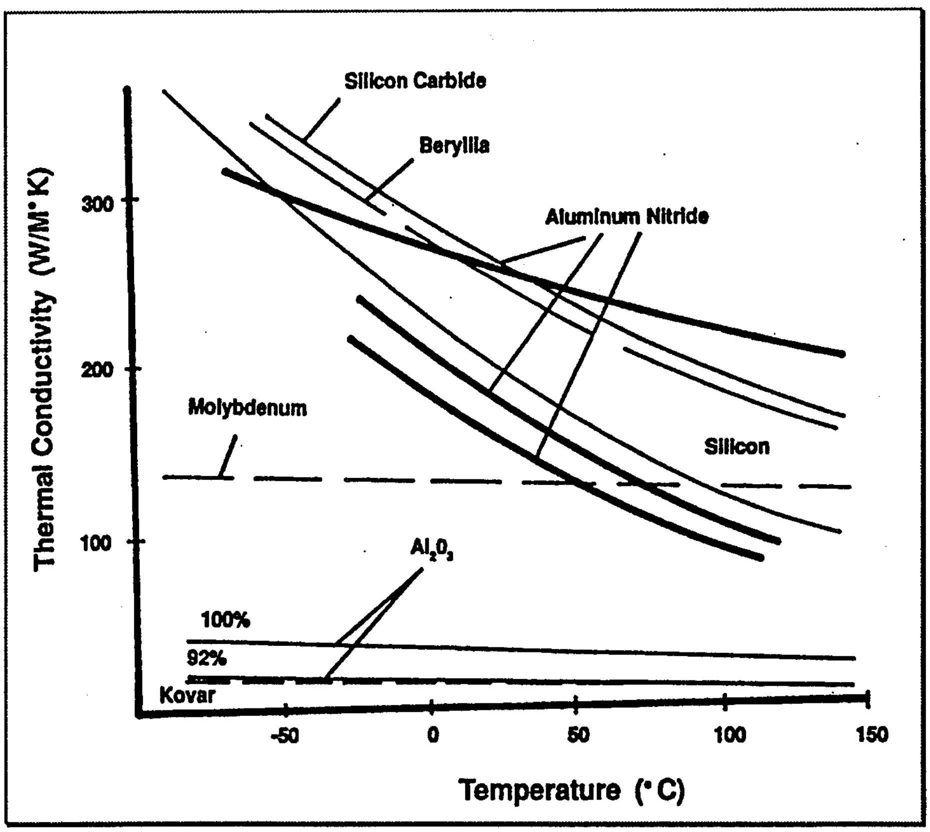

Figure 7. Thermal conductivity of materials in SA package.

Another substrate under consideration is diamond. It is unknown at this point whether the quality and grain structure will prevent substrate usage but YAG's are currently used to cut material. Transmission characteristics will be measured on pieces obtained from NRL to determine suitability. In addition to being an excellent thermal conductor, diamond has opened up the possibility of another application area. Currently die attachment to diamond substrates is a topic for research with traditional solutions including eutectic alloys and adhesives under adaptation. Laser welding could provide a simple solution, when used with a suitable intermediate metal, for GaAs IC's.

CONTINUED EFFORT

Additional effort is required to demonstrate the full commercialization potential for this novel package scheme. Strategic Analysis submitted a Phase II proposal, "High Temperature Packaging for SiC Based on Laser Welded Contacts", to AFOSR on July 31, 1995, for continued funding of this effort. Unfortunately there weren't enough funds available to award a Phase II program. Strategic Analysis, Inc. is currently pursuing alternate means of funding to continue this important research effort. SA can couple directly into the device development research underway at companies like CREE which provided the SiC devices for Phase I. United Technologies Research Center has also shown an interest in our development effort and agreed to work closely with us on any continuing research. UTRC has an existing test set-up designed for high temperature packaging analysis.

SA believes that with a minimal amount of funding three main technical results can be achieved. The first result will be a standard working package which provides a hermetic seal and device integrity into the temperature range of 650°C. This standard package will be fully tested for thermal environments, hermeticity, and mechanical ruggedness, becoming the prototypical high temperature SiC package. Second, a design for a small scale manufacturing system will be developed. This design will include necessary equipment, additional specialty items and drive software for control of laser processing. Design rules will be incorporated into a proto-factory layout. Third, a full cost model of the above package and manufacturing system will be provided and compared to current market niches. Included will be projections of package costs as a percentage of device and manufacturing expenses.

PERSONNEL SUPPORTED

As part of this research a subcontract with George Mason University was issued to Dr. Rao Mulpuri of the Department of Electrical Engineering. His Ph.D. student Andrew Edwards provided the first successful packaging attempts. Both of their salaries and equipment needs have been supported through this contract and an added fund from the Virginia Center of Innovative Technology who matched Strategic Analysis' subcontract. An added benefit from NRL, Dr. Jim Butler, was a direct result of GMU interaction.

PUBLICATIONS

No publications have been generated at this time to protect the proprietary nature of patent rights. Both GMU and NRL are interested in submitting conference papers with Strategic Analysis after a patent application has been filed.

INTERACTIONS/TRANSITIONS

Two significant interactions are under development at this time for commercial implications. Dr. Richard Grzybowski of United Technologies is interacting with Strategic Analysis and joined our Phase II proposal. They will provide testing services and access into the main market thrust, jet engine electronics. The second is relationships to ARPA's program in high temperature electronics under Dr. Xan Alexander. Although this is strictly a materials program at this time, technology maturity is focusing efforts in applications which require packages. Strategic Analysis attended ARPA's program review in this area and is following up to determine applicability of its technology and to generate interest and interaction from ARPA and it's program participants.

Strategic Analysis was a presenter at the STTR review at Wright / Patterson AFB held June of 1995. This meeting assisted in informing potential commercial partners of new technology and provided government feedback on program logistics.

INVENTIONS

As mentioned this concept is part of a recent patent disclosure. A full application is in preparation and will be submitted following new lab results. A preliminary patent search was provided by Thomson Patent Services to reveal existing literature and identify the niche circumscribed by this work. Below is a list of the most significant art. Although some similarities exist a decision to move forward on an application will be made provided additional funding can be realized.

A patent review revealed extensive amounts of art concerning laser welding of metals and ceramics, flip chip bonding, and laser welded contacts. Only a few were related to diamond work. However, none of the patents reviewed combined flip chip and laser welding with a transparent substrate. The major idea is patentable. Neither was die attachment accomplished in this manner; none of the patents pointed to transparent substrates as integral parts of the welded package. Strategic Analysis feels that it has the potential for a basic patent covering several important applications of the technique proven under AFOSR funding.

PARTIAL PATENT LIST

5,407,119 Laser Brazing for Ceramic-Metal Joining, American Research Corporation, Apr. 18, 1995

5,,304,357 Apparatus for Zone Melting Recrystallization of Thin Film Semiconductor Film, Ricoh, Co., Apr. 19. 1994

5,274,210 Laser Bonding Highly Reflective Surfaces, Digital Equipment Corporation, Dec. 28, 1993

5,021,630 Laser Soldering Method and Apparatus, AT&T Bell Laboratories, Jun. 4, 1991

4,732,778 Method of Forming Composite Layer by Laser, Toyota, Mar. 22, 1988

4,541,882 Process for the Manufacture Substrates to Interconnect Electronic Components, Kollmorgen Technologies, Sep. 17, 1985

4,527,040 Method of Laser Welding, U.S. Navy, Jul. 2, 1985